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INCREASING THE DUTY OF WATER

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The importance of obtaining the highest duty of water is apparent when it is realized that the available water supply, when fully developed, will only serve a very small part of the total area of land adapted to irrigation in the arid and semi-arid region, and that wasteful irrigation has been the main cause of over 10 per cent of the irrigated lands becoming unfit for crop production through waterlogging and the accumulation of alkali salts in the surface soil.

It is a significant fact that, while the duty of water is affected by a number of factors, the most important is the value of the water. Where water is most needed for irrigation it is generally most valuable, and if the payment for this water is based on measurements of the volume delivered to the irrigator the water will be used with care and skill, which will make the duty high. On the other hand, where water is plentiful and cheap, and sold on a flat charge per acre, independently of the volume used, or where the irrigator or irrigation company is protected by a water right which entitles him to an excess of water to the detriment of others, there is no incentive for economy in the use of water, crude and wasteful methods of irrigation prevail, and the duty is low. This is well illustrated by the high duty of water obtained in Southern California or elsewhere where the value of water is high, as compared with the lower duty obtained in localities with a more abundant and cheaper water supply. In the Riverside district, in Southern California, where the average annual rainfall is 10 inches, the gross duty on 9,000 acres of land irrigated by the Riverside Water Company's system averaged for a period of seven years a depth of about 2.3 feet. About a third of this tract was in alfalfa and the remainder mostly in citrus orchards, both of these crops having a greater water requirement than deciduous trees. In Pomona, Southern California, the quantity of water applied by pumping on alfalfa fields averaged 2.3 feet for the season of 1904; the mean annual rainfall is about 20 inches, but the rainfall for the preceding winter was only 9.1 inches; yields of 5 to 9 tons of cured hay per acre were common. From citrus orchards the duty on about 3,000 acres in the

Pomona district averaged about 0.8 foot. As compared to these localities in Southern California, the average gross duty for the arid region, as obtained by the Irrigation Investigations of the U. S. Department of Agriculture, is about $4\frac{3}{4}$ acre feet per acre for all crops.

The losses of water which produce a low duty are:

1. The loss which occurs by seepage and evaporation in the conveyance of water in canals.
2. The loss by deep percolation into the soil.
3. The loss of soil moisture by evaporation.
4. The loss of water by surface run-off or waste at the ends of fields or furrows.

CONVEYANCE LOSSES

The difference between the gross duty and net duty represents the extent of the conveyance losses or the efficiency of the system. Measurements made by the Irrigation Investigations of the U. S. Department of Agriculture and by the U. S. Reclamation Service, show that in a new canal system of unlined earth canals the water delivered to the farms is probably no more than 40 per cent of the water diverted. For old canals in good condition the efficiency may be increased to 65 or 70 per cent.

The most valuable general information as regards the extent of conveyance losses are those of the Irrigation Investigations of the U. S. Department of Agriculture. From series of measurements on 73 ditches in the western states,¹ the average loss per mile of ditch was found to be 5.77 per cent of the entire flow; the measurements range from a maximum loss of 64 per cent to a slight gain, in some cases due to the rise of the water table. Large canals in general lose less in proportion than small ones. The measurements average about 1 per cent for canals carrying 100 cubic feet per second or more, about $2\frac{1}{2}$ per cent for canals carrying 50 to 100 cubic feet per second, $4\frac{1}{2}$ per cent for canals carrying 25 to 50 cubic feet per second, and $11\frac{1}{4}$ per cent for canals carrying less than 25 cubic feet.

For some purposes it is preferable to know the extent of seepage expressed in cubic feet of water per day per square foot of wetted area of the canal. This is equivalent to stating the depth of water in feet lost each day. Mr. F. W. Hanna, engineer of the Boise project, Idaho, who has assembled seepage data pertaining to different sections of the West, assumes seepage losses of 0.5, 1.0, and 1.5 cubic feet of water per day per square foot of wetted area respectively for rather impervious, mediumly impervious, and rather pervious soils. The conveyance losses are due to evaporation as well as percolation, but, contrary to a common belief, the losses by evaporation from flowing

water in a canal are insignificant when compared with those of seepage. The average daily evaporation for the irrigation season will generally not exceed about one-quarter inch per day, which is from 25 to 75 times less than the rates of seepage losses previously given. The greater proportionate conveyance loss of water for small canals than for larger ones shows the economy of water to be gained by adopting the practice of rotation for the operation of the smaller laterals at least and by planning the systems so as to shorten as much as possible the mileage of smaller ditches. The conveyance loss can be further decreased by the proper location of canals, so as not to pass through very porous ground, and by not using too deep a cut where such a cut will reach a porous subsoil.

EFFECT OF DIFFERENT LININGS ON SEEPAGE

To prevent the seepage obtained in unlined canals, linings of different materials have been tried. Those used or experimented with are concrete, wood, oils, and clay puddle. From investigations made by the writer in 1906 for the Irrigation Investigations and the California Experiment Station, and from more recent experience on the efficiency of the different types of linings, the following results can be anticipated:

1. A good oil lining, constructed with heavy asphalt road oil, applied on the ditch sides and bed at the rate of about 3 gallons per square yard, will stop 50 to 60 per cent of the seepage.

2. A well constructed clay puddle lining is as efficient as a good oil lining.

3. A thin cement mortar lining about 1 inch thick, made of one part cement to four of sand, will prevent 75 per cent of the seepage.

4. A first-class concrete lining, 3 inches thick, made of one part of cement to two of sand and four of gravel, will stop 95 per cent of the seepage.

5. A wooden lining, when new, is as efficient as a concrete lining, but after two or three years repairs and maintenance will become an important item, and by the end of eight or ten years it will necessitate complete renewal.

The cost of an oil lining where oil can be bought at California prices (about 2 cents a gallon) is about $\frac{1}{2}$ cent per square foot. Cement mortar lining 1 inch thick costs about 2 to 4 cents per square foot. Cement concrete 2 inches thick costs from about 4 to 6 cents, and 3 inches thick from about 6 to 8 cents a square foot. These prices do not include the trimming and preparation of the ditch before the lining is put on, which would add from $\frac{3}{4}$ to $1\frac{1}{2}$ cents per square foot. The cost of a clay lining depends greatly on the nearness of the canal to suitable clay. If clay is close at hand it can be hauled and spread on the canal, then either tramped in by cattle or worked in by drag-

ging chains over it, at a cost of less than 1 cent per square foot, but there are localities where enough money has been spent on clay linings to pay for a good concrete lining. Wooden lining has been used in very few cases, and the cost of such a lining built of 2-inch lumber nailed on sills and side yokes will often be as much as that of a 2-inch concrete lining and not nearly as durable.

The disadvantages of the cheaper linings are the following: An oil lining stops only a part of the seepage losses, and while it will resist erosion well, it probably will not prevent the growth of weeds for more than one season unless a high velocity is used, and it will not stop the activities of burrowing animals. Oil linings have not been sufficiently tested to determine their durability. Clay puddle will not prevent the burrowing of animals and weeds grow rapidly, especially since the velocity of the water must be small in order to prevent the eroding or washing of the lining.

ADVANTAGES OF CONCRETE LINING

A concrete lining has none of the above disadvantages, and it meets the requirements of a good lining better than any other material. The only objection is its higher first cost. But where water is valuable its expense is well justified. In Southern California the use of concrete lining dates from about 1880, when the increasing value of water made it necessary to do away with losses. Since that time practically all canals in that section have been lined with concrete, and in some cases replaced with concrete pipes. Until recently very little concrete lining had been used outside of that region, but during the last few years concrete lined canals have been constructed on many of the projects of the U. S. Reclamation Service and on numerous private projects. There are now many examples in California, Oregon, Nevada, Washington, Idaho and other States, and during the past three years some good work has been done in British Columbia.

The feasibility of using concrete linings will depend on the extent and value of the water loss and on the necessity for prevention of waterlogging of the land below by the seepage water. Other benefits which must be considered are the decreased cost of maintenance and operation and the greater safety. There are no weeds to contend with, no breaks to mend, and consequently the cost of patrolling is largely eliminated. It must also be remembered that a higher velocity can be given to the water in a concrete lined canal, and a smaller and better form of canal can be used, which, especially on a sidehill, will materially decrease the cost of excavation. But even when only the value of the water loss is considered, it does not require a large loss nor a very high price for water for this annual value to represent the interest and depreciation on a capital sufficient to put in a first-class concrete lining.

LOSS OF WATER BY DEEP PERCOLATION

This loss is largely dependent on the distance the water is run over the field or in the furrows, and on the volume or head of water used. Porous soils underlaid with gravel are most difficult to handle to prevent this loss, but it may be much decreased, if not entirely

prevented, by proper irrigation practice using frequent light irrigations instead of heavy irrigations. The extent of the loss is illustrated by the following examples:

Experiments carried on by the Irrigation Investigations of the U. S. Department of Agriculture in a Southern California citrus orchard, irrigated with furrows 660 feet long, showed that at the upper end of the furrows the water had percolated down to a depth of 27 feet, while for the lower half of the furrows the depth of percolation was only about 4 feet.* Experiments made by the Irrigation Investigations have, according to Mr. Tallman, proved conclusively that fully 50 to 75 per cent of the water applied to the gravelly soils of the Upper Snake River Valley in Idaho is lost by deep percolation beyond the reach of plant roots.

The U. S. Reclamation Service found that on a very porous gravelly soil which was flooded with runs 515 feet long, the depth of saturation was 6.5 feet at the upper end and 2.5 feet at the lower end. On a soil of wind blown sand and ash underlaid with coarse sand, flooded with runs 1350 feet long, the depth of saturation at the upper end was 12.4 and at the lower end 4.4. In each case the same degree of saturation at the lower end could have been obtained with 33 per cent less water by making the runs one-quarter of the lengths given in each case.

To decrease the loss by deep percolation, the remedy is to divide the field or orchard into short furrows or runs, the length depending on the character of the soil, and to run the water more quickly in the furrows or over the fields by using larger heads, especially for porous soils. This will usually require the practice of rotation, at least for the smaller farms or orchards, which has the added advantage of decreasing the conveyance losses and of shortening the length of time involved in applying the water.

The benefits derived from short runs and comparatively large heads is well illustrated by the following example:

The irrigation Investigations in Idaho found that where the length of run was 2359 feet it required an average depth of flooding of 1.6 feet for a satisfactory irrigation, while with runs of 237 feet the average depth of water for a thorough irrigation was only 0.7 feet, or a saving of 56 per cent.

It is probably safe to assume that the loss due to deep percolation will average no less than 25 per cent of the water delivered to the farm.

LOSS BY EVAPORATION OF SOIL WATER

This loss is dependent on many factors, some of which, such as the method of irrigation, the time and frequency of cultivation, can be controlled by a skillful irrigator. The extent of this and the degree to which it can be diminished has been the subject of extensive experiments by the Irrigation Investigations of the U. S. Department of Agriculture, carried on by the use of tanks at a number of stations in the arid states.† The average of the results obtained at six of these

* U. S. Dept. Agr., Office Exp. Sta., Bul. 203.

† U. S. Dept. Agr., Office of Exp. Stas., Bull. 248.

stations show that for soils receiving a 6-inch depth of water on the surface the evaporation loss for a period of 30 days was 2.14 inches for soils not cultivated after the irrigation, and 1.58 inches for soils cultivated 6 inches deep three days after the irrigation. Cultivation caused a saving of 25 per cent of the loss.

Where the crops are grown in furrows, the loss by evaporation can be further diminished by using deep furrows, which do not wet the surface to the same extent as shallow furrows or surface flooding, thus permitting cultivation soon after the irrigation. The average results at two of the above stations show that for soils irrigated with a 6-inch depth of water applied by surface flooding and in furrows 3, 6 and 9 inches deep, followed by cultivation, the evaporation loss was 1.25 inches for the surface flooded soil, 0.99 inch for the soil irrigated with 3-inch furrows, and 0.72 inch for the soil irrigated with 9-in. furrows.

These results indicate that with conditions similar to those where the above experiments were conducted, the evaporation from a soil surface flooded will probably be about 35 per cent of the water applied, when no cultivation follows the irrigation; while with a soil irrigated with furrows 9 inches deep, followed by cultivation, the loss will be about 12 per cent of the water applied. These losses were for bare soil; the effect of shading by plants would be to decrease the soil evaporation and perhaps give a probable loss of 25 per cent for soils planted to such crops as do not permit cultivation.

LOSS BY SURFACE RUN-OFF

This loss represents a waste, the extent of which is dependent on the skill and care taken in the preparation of the land for irrigation and in the application of the water. On many farms this loss does not exist, but it is frequently not prevented. On eight of the projects of the U. S. Reclamation Service, in the Northern division, the loss averaged about 8 per cent of the water applied. On the Boise Project the run-off from nine tracts of grain and alfalfa ranged from 4 to 18 per cent, averaging 11 per cent of the water applied.

CONCLUSION

These losses when assembled indicate that for an average irrigation system the conveyance loss may be fully 40 per cent of the water diverted, and of the amount delivered 25 per cent or more may be lost by deep percolation, 25 per cent may be lost by soil evaporation, and 10 per cent lost by surface run-off; the total of these losses would be 76 per cent of the water diverted.

Where the value of the water will justify it, concrete linings will decrease the conveyance loss to about 5 per cent of the water diverted; the deep percolation loss, where water is used with care, could be very nearly entirely prevented, and would probably not exceed 10 per cent of the water applied; the evaporation loss, where the crops will permit deep furrow irrigation and cultivation, will probably not exceed 15 per cent of the water applied; the surface run-off loss or waste can be eliminated. The total losses for these conditions will be about 27 per cent.

To sum up these results based on experiments typical and representative of irrigation practice in the West, it is conservatively estimated that 76 per cent of the water supply diverted from the stream is wasted or lost, but that by adopting means of conservation which have been used successfully in irrigated districts where water is valuable the waste and loss may be so decreased that the water supply will serve two or three times the area served with the irrigation methods now prevailing in many sections.

The extent to which the conservation methods above outlined will be adopted will depend largely on the value of water. Throughout the arid region the increasing demand for water and the greater cost of development are increasing the duty of water. The ill effects of low duty of water have been forcibly brought to the attention of the irrigator by the waterlogging and damages of alkali in nearly every irrigated section, and have increased the duty at least on those lands which are affected or which are liable to be affected, as indicated by the rise of the water table. The increase in duty due to these causes, as well as to the fact that seepage losses are smaller with an old canal system, is well illustrated by the experience on the Sunnyside system in the Yakima Valley, Washington, and the Modesto and Turlock districts in California, where drainage systems have been found necessary and are partly constructed. On the Sunnyside canal system the gross duty increased from 11.4 acre feet per acre when 6883 acres were irrigated in 1898, to 4.57 acre feet per acre when 47,000 acres were irrigated in 1909. On the Modesto and Turlock systems the gross duty in 1911 was more than twice as high as in 1904, but the volumes diverted in 1911 were still sufficient to give a gross duty of 4.58 acre feet per acre on the irrigated lands of the Modesto and Turlock systems.

The courts can do much toward increasing the duty of water by limiting water rights to a beneficial and economical use. As reflected in the early cases, our Western courts believed that one should be allowed the amount of water he had been using, but this is not the rule today. The change in the attitude of the courts is very well shown by the following quotation from the Supreme Court of Oregon in the case of *Hough V. Porter* (98 Pac. 1102), decided January 5, 1909:

"In some instances a larger amount than the quantity here permitted was originally diverted; but merely because in the earlier history of the vicinity large quantities were diverted and applied, notwithstanding the ditches first constructed were of sufficient capacity to carry such supply, does not necessarily indicate that such was needed. Again, it has been so often demonstrated as to become a matter of common knowledge that lands after years of irrigation do not require the amount which, when first applied, was essential to the successful growing of crops thereon. This law of nature, added to the improved methods, greatly reduced the quantity now required. See *United States vs. Conrad Invest. Co. (C. C.)* (156 Fed. 123, 130). . . . In this arid country such manner of use must necessarily be adopted as will insure the greatest duty possible for the quantity available. *Van Camp vs. Emery* (13 Idaho, 202, 89 Pac. 752); *Anderson*

vs. Bassman (C. C.) (140 Fed. 14, 27). The wasteful methods so common with early settlers can, under the light most favorable to their system of use, be deemed only a privilege permitted merely because it could be exercised without substantial injury to any one; and no right to such methods of use was acquired thereby."

In the recent case of Little Walla Walla Irrigation Union vs. Finis Irrigation Company (124, Pac. 668), decided July 2, 1912, the Supreme Court of Oregon again refers to this subject and states: "It is the policy of the law that the best methods should be used and no person allowed more water than is necessary, when properly applied, and thus a larger acreage may be made productive by its extended application."

In this last case, however, the Supreme Court of Oregon continues its argument to show that old water users in effecting a saving of water cannot be compelled to adopt other methods of use which would be so expensive as to absorb all the profits, and concludes: "Here the users have acquired the land and applied the water, which are valuable under present conditions, and their rights therein are vested, and we can require them only to use the water economically and reduce the quantity to a minimum by reasonable and cheap methods according to their situation and condition."

Another illustration of the present tendency of the courts to insist upon a higher duty is the recent case of Doherty vs. Pratt (124, Pac. 576) decided by the Supreme Court of Nevada June 21, 1912:

"The rule as to reasonable and economical use of water applies as well to methods of diversion as it does to the application of the water to the land itself. The topography of the county and the character of the soil through which water is conveyed to the point of use must, of course, be taken into consideration in determining the amount of water to which an appropriator is entitled, but an appropriator has no right to run water into a swamp and cause the loss of two-thirds of a stream simply because he is following lines of least resistance. Such a method of diversion would not be an economical use of the water providing another reasonable method, under all the circumstances, could be devised to avoid such loss, even though it occasioned some additional expense to the appropriator. It is as much the province and duty of the trial court to determine whether the methods adopted for diversion are reasonable and economical under all the facts of the case as it is to determine the amount of water required by the appropriator at the place of use."

Large irrigation projects are now being constructed in localities where the use of water under the old private system has been wasteful, due to great losses in transmission and lax methods of application. The new enterprises should set a standard of economy in use to which, when proved practical, the old system must ultimately conform. It is, therefore, imperative, if the highest duty is to be attained, that the new enterprise be so constructed that it will eliminate transmission losses as far as practicable under the conditions existing at present, and that it should be so operated as to allow only the most effective methods of applying water to the land under cultivation.